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AIRCRAFT TRANSPARENCY OPTICAL QUALITY: NEW METHODS OF MEASUREMENT

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AFAMRL-TR-81- 21

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FOR THE COMMANDER

CHARLES BATES, JR.
Chief
Human Engineering Division
Air Force Aerospace Medical Research Laboratory

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This report describes some traditional methods of measuring distortion in aircraft transparencies. A more expedient means of interpreting photographic distortion data via computerized digital analysis of the photo is also described. Finally, two new devices are introduced: one that measures angular deviation with extreme accuracy in a relatively small space and one that brings laboratory accuracy to field optical measurements. These latter devices employ state-of-the-art components and knowledge to provide extreme accuracy and usefulness.

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PREFACE

The devices described in this document and the research which contributed to their development were initiated by the Air Force Aerospace Medical Research Laboratory (AFAMRL), Human Engineering Division, Wright-Patterson Air Force Base, Ohio, under Work Unit 7184-18-02. Funding for this effort was provided by Air Force Wright Aeronautical Laboratories, Flight Dynamics Laboratory, Vehicle Equipment ADP Branch. Computer software engineering and fabrication support were provided by Systems Research Laboratories, Inc. (SRL), Dayton, Ohio.

The authors wish to express their appreciation to these individuals who provided encouragement and assistance throughout this effort, including Major Robert Eggleston, who contributed much to the initial idea; Ken Smith, who designed and constructed the electronics in the angular deviation receiver; and George Dabbs, who was responsible for much of the design and fabrication of the devices.

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Section 1
INTRODUCTION

The optical "side effects" of aircraft transparencies include distortion, binocular distortion, angular deviation, displacement, haze, transmission loss, multiple imaging, rainbowing (birefringence), and minor defects. Most of the distortion related effects, as well as multiple imaging and birefringence are recorded using some type of grid board photographic technique. Haze and transmission loss are usually measured with a hazemeter under standard test conditions. Angular deviation may be measured with the aid of a telescope (or theodolite) or a laser. This report will introduce a new way to examine some of the data obtained with standard photographic distortion measures and will describe two new devices which employ state-of-the-art methodology to obtain critical optical data from aircraft transparencies.

Section 2
GRID BOARD PHOTOGRAPHY

There are several ways to produce grid board photographs to determine the distortion in a transparency:

1. Single Exposure Techniques

   a. Single Aperture
   b. Multiple Aperture

2. Multiple Exposure Techniques

   a. With/Without Transparency
   b. Right/Left Eye Views

Single exposure techniques are used in many aircraft transparency quality control procedures. In this technique, a photograph of a specified grid board is made with the transparency, camera, and grid board at specified distances. A portion of the field of view includes an area of grid board outside the area of the transparency. If a single aperture is used, distortion will appear on the final photograph as a bending or blurring of the grid lines. If multiple (usually two, sometimes three) apertures are placed in front of the camera lens, the final photograph will show distortion as line splitting.

One type of multiple exposure technique makes a double exposure of the grid board: one exposure without the transparency in place and one with. The final photo shows a plethora of lines, one set being undistorted and used as a reference, while the other set contains the distorted image. "Binocular" photographs may also be made. In this case, the camera is placed in a position equivalent to the pilot's right eye; and a photo of the grid board is taken through a red filter. The process is repeated with the camera at an equivalent left eye position with a green filter. When the double-exposed color negative is processed, the separation between the red and green lines

indicates the "binocular residual distortion" which the visual system must deal with in order to maintain single simultaneous binocular vision.

ANALYSIS OF GRID BOARD PHOTOS, GRID LINE SLOPE

Once the photographs have been taken, the problem of analysis and interpretation remains. A common method of reducing the data to a more understandable format involves the determination of grid line slope. In this method, the enlarged photograph is usually affixed to a drafting board and aligned such that undistorted grid lines are horizontal. Drafting instruments are then used to measure the slope (deviation from true horizontal over a specific distance) of lines photographed through the transparency. This determination is made for several horizontal and vertical lines. The maximum slope is recorded as a ratio, such as 1 in 10, indicating the tanget of the angle between the distorted line direction and a true horizontal (or vertical). Grid line slope can also be measured on a double exposure by using the undistorted grid as a reference.

LENSING AND DISPLACEMENT GRADE

A refinement of the grid line slope method is used to determine distortion in F-111 windscreens. This refinement introduced two new concepts, those of lensing and displacement grade (ATP 601-E, 1979).

Lensing or Lens Factor (LF) measures are made from the single aperture single exposure photos described above. The baseline measure is a count of grid squares per inch in an undistorted portion of the picture. Several similar counts of grids per inch are then made of grid areas photographed through the windscreen. The most deviant of these latter counts is then compared to the baseline by dividing the larger number by the smaller. The result is then cubed to increase the "spread" between findings. This result is designated as the Lens Factor.

Displacement Grade (DG) measures are made from the same photos used to d termine LF. For any area of interest, the maximum vertical displacement

of a horizontal line is measured in hundredths of an inch. This value is added to the maximum horizontal displacement of any vertical grid line. The sum is then multiplied by 1000 to yield the Displacement Grade value for the area measured.

DIGITAL PROCESSING OF GRID BOARD PHOTOS

A 1979 study undertaken by the University of Dayton Research Institute (UDRI), while under contract to AFAMRL, indicated the greatest source of error for measurements of this type lies in the physical measurement of the grid line slope (Harris, 1981). There could exist a wide variability among readings since the slopes are actually segments of curved lines rather than straight lines, the ability to measure any set of lines repeatedly is a matter of experience, and there is an inherent error in the drafting instruments. AFAMRL found a partial solution to this variability problem by employing an electronic digitizer to sample salient portions of the photograph. The technician simply places a "bug" consisting of a cross hair under a magnifying lens on a series of grid line intersections. When alignment has been achieved, he presses a button to record the position of the "bug." This position is recorded to an accuracy of 0.005 inch and stored in digital format in a computer. The digitized data are then processed by the computer to yield Displacement Grade, Lens Factor, and grid line slope values without the tedium of using drafting instruments and interpolating thousandths of an inch from boxwood scales.

Investigation of the digitizer method showed that equivalent LF and DG readings were obtained from photographs measured by experienced quality control personnel using the drafting instruments and relatively inexperienced technicians using the digitizer. The greatest source of error in the latter method appeared to be the tremor in the technician's hand! A significant time savings was also realized by using the computer method. Unfortunately, the main objection to any grid line slope measure made from a photo still existed--the technician had to estimate a tangential position for a distorted segment of a curve. In other words, if grid line slope were to be measured, where on the curved line should the bug be placed?

Section 3
DIRECT MEASUREMENT OF ANGULAR DEVIATION

The authors decided to bypass the problems inherent in various grid line slope measures by directly measuring the angular deviation of a light ray passing through the transparency. Distortion has often been defined as the rate of change of deviation. Deviation is defined as the angular change of direction of a light ray as it passes through the transparency. If we could find a sufficiently sensitive and accurate method of measuring angular deviation and employ this method with sufficient measurement density, we should be able to determine the distortion in any transparency.

Whenever a ray of light passes through a transparency at an angle other than the normal (a "normal" is a line drawn perpendicular to the transparency surface), several events occur. (See Figure 1.) One of these events results in the lateral displacement of the ray by a relatively small and constant amount. This lateral displacement is usually operationally insignificant beyond a few meters, but contaminates angular deviation measures made with short "throw distances."

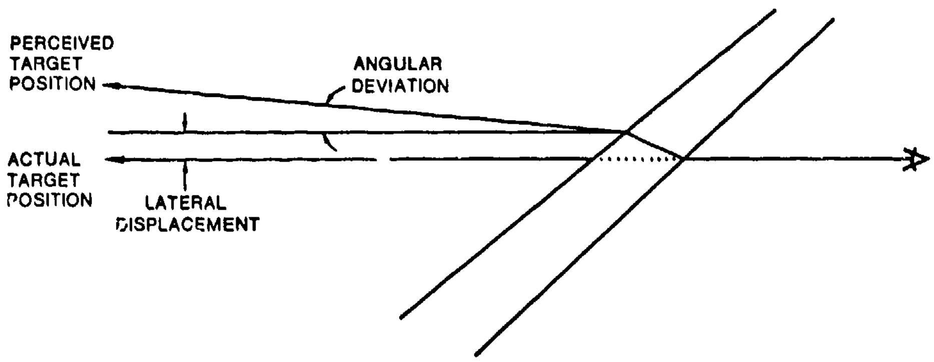

Figure 1. Lateral Displacement and Angular Deviation Effects of Aircraft Transparencies

A second event causes the light ray to undergo an angular directional change. This angular error can be quite significant when considering its effect on apparent target position as seen by the pilot. For each milliradian (mr) of error, the target's true position will be displaced from its apparent position by 1 foot for each 1000 feet of range. In other words, a transparency inducing a mere 10 mr error can move the apparent position of a target located 3000 feet away a distance of 30 feet; more than enough to miss the target.

Angular deviation is caused by both relatively local areas of nonparallelism, as well as overall nonparallellism of the surfaces of the transparency. The angle of installation, pilot's line of sight, and other factors contribute to modifying the severity of this problem. The end result of this problem is to produce a nonlinear mapping of external objects. In other words, the actual position of the target does not correspond with its apparent position as seen from the cockpit.

Several methods presently exist for determining the angular deviation inherent in an aircraft transparency. One method uses a telescope or theodolite to view a reference target. The transparency is then interposed, and the target is viewed through several predetermined locations of the transparency. The difference in angular position of the target as seen with and without the transparency is a measure of the total deviation induced by the transparency. This total deviation measure includes the effects of both lateral displacement and angular deviation.

Another problem with telescope-based systems arises when the telescope is used to look through an area of transparency which has a poor Modulation Transfer Function (MTF), resulting in a blurring or doubling of the images. MTF and anamorphic lensing problems introduced by the transparency make measurements through certain areas extremely difficult, if not impossible.

An alternative to the telescope method involves projecting a laser beam through the transparency onto a screen. The position of the laser spot is

compared to its position prior to insertion of the transparency, and appropriate mathematical exercises would yield a figure representing total deviation. Although MTF and lensing would influence the size and shape of the spot, it appears easier to estimate the center of the distorted spot than to see the degraded image in a telescope-based system.

Both telescope-based and laser-based systems commonly reduce the effect of lateral displacement by viewing (or projecting) over a long distance--approaching 100 feet. For systems of this type, the total deviation measured is primarily due to the angular deviation and not the displacement. For this reason, these systems are preferable. However, an obvious disadvantage of systems incorporating long throw distances is the requirement for clear space which may conflict with other functions of the facility in which the test apparatus is housed.

The laser-based system has been used to make angular deviation maps of F-111 windscreens as they were held perpendicular to the laser beam. A rather complicated process of drawing vectors and overlaying templates was intended to be used as an indication of the severity of angular deviation after the windscreen was returned to its installed position. Acceptance/rejection criteria were based on a relatively low density mapping of the windscreen (ATP 601-E, 1979).

A somewhat higher mapping density is used for F-16 canopies, and the canopy is measured while held in the installed position. The advantage of measuring angular deviation of the transparency while it is mounted in the installed position is that the measured values represent exactly what is seen by the pilot. Both laser-based and telescope-based systems are used. USAF acceptance/rejection criteria are 1 mr RMS and 3 mr maximum deviation from a best fit curve of several data points. All data are recorded manually, including azimuth and elevation position as well as azimuth and elevation deviation for up to 73 positions of each canopy.

The University of Dayton Research Institute compared grid line slope measures of photographs to point-by-point measures made with a telescope of 90-inch focal length (Harris, 1981). Their conclusions follow:

In the use of a slope technique for evaluation of a windscreen instead of point-to-point measurements, the results will not describe the amount of constant displacement or deviation which may exist due to the windscreen geometry. Also, there is less accuracy obtainable from the grid slope method than from the point-by-point method. The first problem is due to the ambiguity of where to measure the slope, as mentioned previously. There is also a direct problem of measurement of the photographic data. If we take the limit of accuracy of the point-by-point system to be the accuracy to which the target can be measured (±1/16 inch for the 90-inch focal length lens), this gives accuracy of close to ±1 minute of arc. To realize this same accuracy on a photograph printed to 16 grid squares per inch, measurement must be made to less than .004 inch. This accuracy would be very difficult to obtain.

The grid board photography techniques are simple to perform in the laboratory and provide the overall distorting information in one hard copy for the record. The effort involved in the grid board photography occurs when the measurements are made. The desired accuracy and repeatability are not easy to obtain. On the other hand, point-by-point techniques are very laboratory intensive, which can be hard on the person taking the data (an effect which may itself introduce some errors). As mentioned before, this effort would be greatly lessened with a movable mount, automated mapping technique. There are still some out-of-the-laboratory computations required to get the grid board information (which are not direct) since the pictures must be evaluated to get the desired data.

The procedure for taking the grid board photographs is straightforward. However, because many of the photographs must be compared to each other or to a standard photograph, there are strict requirements on stability of the camera and repeatability of the position of the camera because any vibration will produce fuzzy pictures. A little vibration from the camera shutter is usually of little concern; however, in attempting to read these grid board photographs to less than 0.01 inch, a shakey tripod will allow this much movement to occur. Another stability problem was encountered in taking binocular photographs where the camera must be translated between the two photographs without changing its longitudinal position (and hence the focus). Most camera tripods will "tilt" from side to side if the weight of the load is not evenly centered on the tripod. A heavy-duty tripod was required to take correctly registered binocular photographs (translating the windscreen laterally). These photographs indicate that the windscreen does, in fact, introduce a "tilting" of the grid board image, which cannot be accurately measured if the tripod itself may also be tilting.

These problems with camera stability also introduced a repeatability error. If the photographs of the grid board are to be compared, a stable and repeatable reference point with respect to the grid board must be maintained.

Another major source of error in taking the photographs is caused by focus errors. Any set of exposures which are to be compared later by overlaying the negatives must all be taken with the same focus setting on the camera. This is because any focus error (due to focus setting changes or tilts and translations of the camera relative to the grid board) will cause a change in magnification of the grid board. Any changes in the size, shape, or character of the brid board should be due to the windscreen under test. <u>The windscreen should be the only optical variable</u>.

From this information, we may conclude that a properly executed point-by-point angular deviation measurement, if taken with sufficient density, would be a very reliable metric of both angular deviation and distortion. The major disadvantage appears to be a requirement for significant work on the part of the person taking the readings, with an attendant possibility of error and significant time usage.

In an attempt to obtain high density, extremely accurate angular deviation measures of F-16 canopies while maintaining a relatively small space requirement and relatively low technician workload, the authors have produced an angular deviation measurement device which both exceeds our expectations and should meet the most stringent demands for optical quality measures in any aircraft transparency requiring strict optical control (Task, 1979, 1980).

DESCRIPTION OF THE DEVICE

Figure 2 shows a pictorial top view of the optical system. From left to right, light from an incandescent lamp is collected by a condensing lens to illuminate the target slide. The projection lens is located one focal length from the target slide such that it collimates the image of the target slide. This portion of the system is positioned such that the projection lens is approximately at the design eye position or observer position for the transparency under test. The remainder of the system (the receiver) is located on the other side of the transparency.

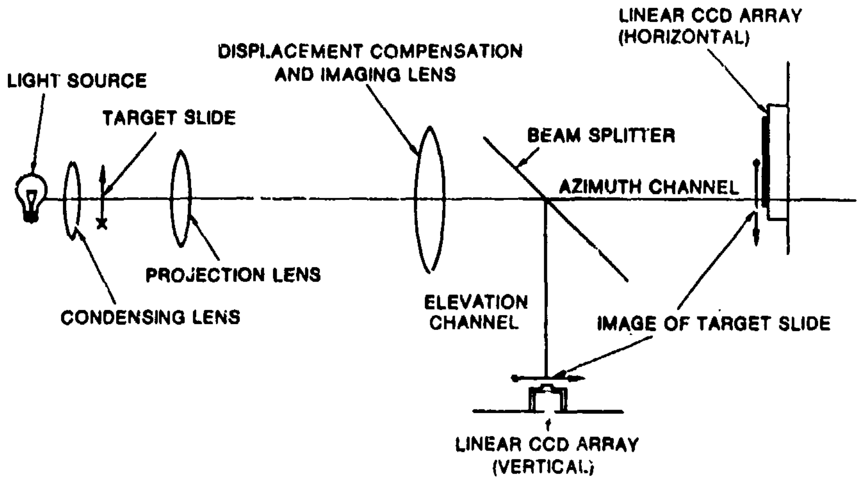

Figure 2. Pictorial Layout of Windscreen Angular Deviation Measurement Device (the windscreen to be measured is positioned between the projection lens and the displacement compensation lens)

The receiving lens compensates for lateral displacement (thus eliminating that error source) and images the target slide one focal length away. A beam splitter divides the light into two approximately equal intensities: one channel to measure azimuth (horizontal) deviation and one to measure elevation (vertical) deviation Except for a 90-degree rotation about the optical axis, both channels are identical. In each channel a segment of the target slide image intersects a charge coupled device (CCD) linear array and its associated electronics. The positional change of this intersection between windscreen and no windscreen conditions is mathematically related to the angular deviation of the windscreen at the point measured.

THEORY OF OPERATION

The target slide is shown in Figure 3. The dimensions and location of the "L" are not critical; however, the stroke width of the "L" must be uniform to reduce error. The image of the "L" is produced at the plane of the CCD array. The array is offset from the optical axis so that only one leg of the "L" intersects the array as shown in Figure 4.

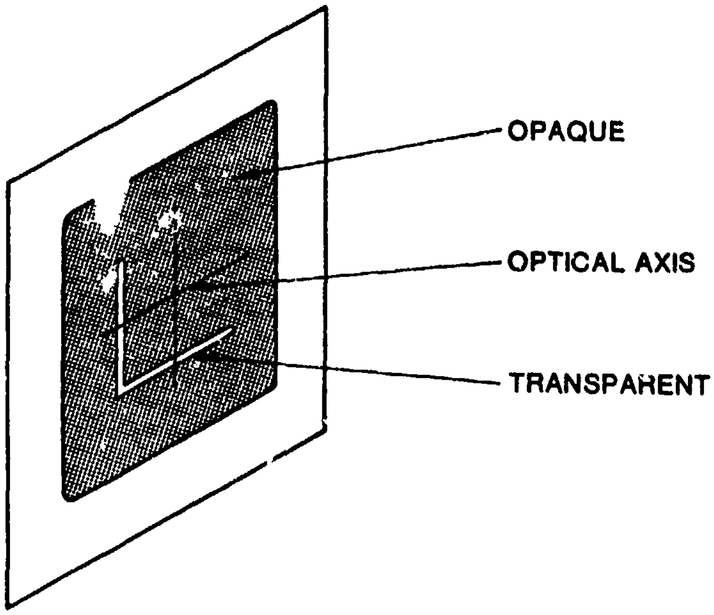

Figure 3. Target Pattern for the Projector Half of the Angular Deviation Measurement Device

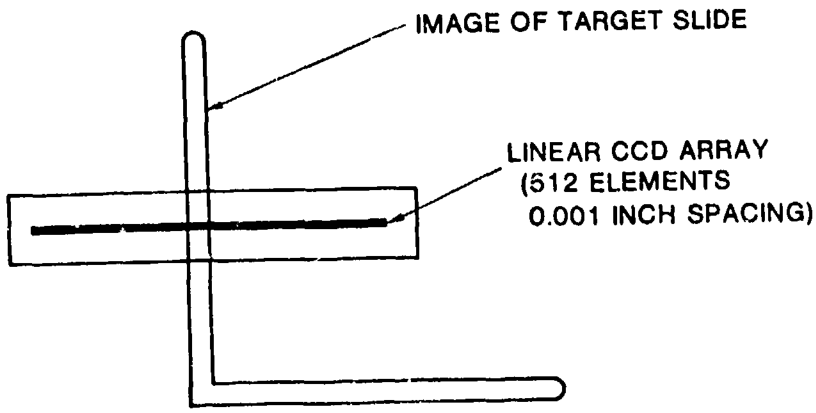

Figure 4. Intersection of the Image of the Target Pattern with the Vertical Channel CCD Array

As the individual CCDs are sampled, the electronic output signal appears as shown in Figure 5. Typically, several CCD elements are activated as shown by the series of spikes between A and B in Figure 5. To ascertain the location of the center position of the "L" segment, a counter counts CCD clock pulses until the output of the array exceeds a detection threshold level. The first counter stops counting at this point (A) and a second counter starts counting. The second counter counts every second pulse until the output of the array falls below the threshold (B). The counts from both counters are added. This resulting count corresponds to the center of the "L" leg segment. This position is shown as (C) in Figure 5. Equation (1) shows this relationship.

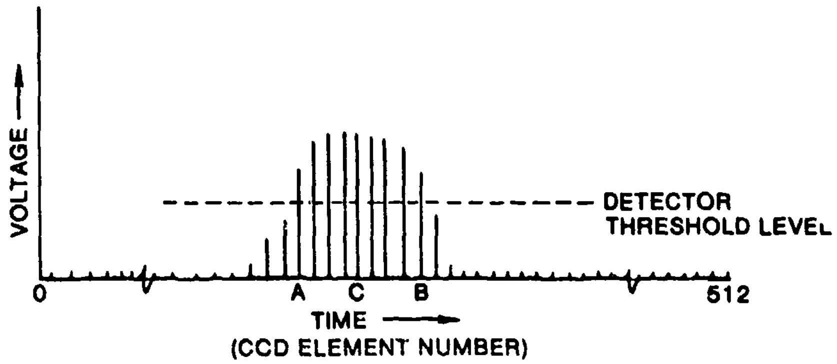

Figure 5. Signal Output from the CCD Array Electronics Showing the Pulses Resulting from the Intersection of the Target Pattern Leg Segment and the CCD Array (A--B)

$$C = A + \frac{B-A}{2} \tag{1}$$

where:

C = center position CCD element number

A = front edge of "L" element number

B = back edge of "L" element number

The accuracy capability of the optical system is determined by the lens quality of the projection lens (L_1) and the receiver lens (L_2), the spacing of the CCD array elements and the focal length of L_2. The minimum detectable angular deviation is determined by Equation (2).

$$\alpha = \arctan \frac{h}{f_2} \tag{2}$$

where:

α = minimum measurable angle

h = spacing of CCD array elements

f_2 = focal length of L_2

For the device that was fabricated and tested, h was 0.025mm and f_2 was 360mm. Thus, from Equation (2) the "least count" was 0.07 mrad. It is obvious from Equation (2) that the minimum measurable angular deviation can be improved by increasing the focal length, f_2, or decreasing the CCD element spacing.

DESIGN CONSIDERATIONS

Although the separation distance (S) between the projector and the receiver is not critical and does not affect the measurement accuracy, it does have an effect on the light energy at the image plane. As shown in Figure 6 the diameter of L_2 is greater than the diameter of L_1. This increases the angular coverage at the image plane that is not vignetted. The largest distance from the optical axis at the image plane that does not incur vignetting is also shown in Figure 6 and is calculated with Equation (3).

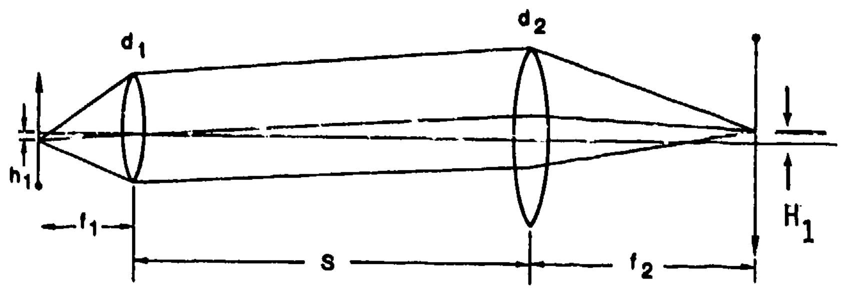

Figure 6. Projector-Receiver Ray Trace Showing Maximum Distance h_1 Possible Without Incurring Vignetting at Lens L_2 Du to Diameter d_2

$$H_1 = \frac{d_2 - d_1}{S} f_2 \tag{3}$$

where:

H_1 = maximum unvignetted ray height at image plane

d_2 = diameter of lens L_2

d_1 = diameter of lens L_1

f_2 = focal length of lens L_2

S = separation between projector and receiver

From Equation (3) it is apparent that it is desirable to keep "S" small and d_2 much larger than d_1 to achieve a large value of H_1. The focal length f_2 can also be increased (which increases accuracy as well) except that the image irradiance changes as a function of $1/(f_1+f_2)^2$. Thus, the irradiance drops as the square of the focal length as accuracy and vignetting effects improve linearly with f_2.

Figure 7 shows the optical ray trace for 50 percent vignetting.

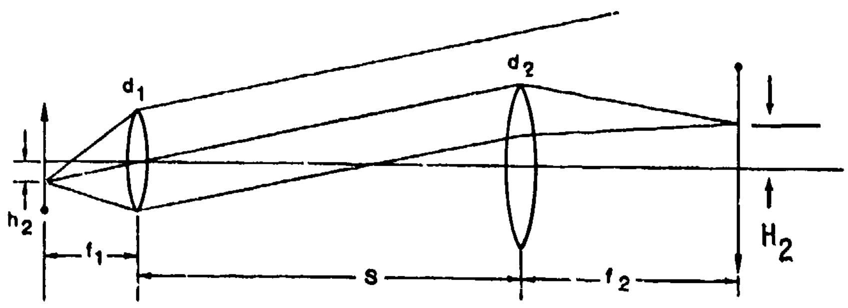

Figure 7. Projector-Receiver Ray Trace for 50 Percent Vignetting Due to Lens L_2 Diameter d_2

The 50-percent vignetting ray height at the image plane is given by Equation (4).

$$H_2 = \frac{d_2}{S} f_2 \tag{4}$$

where:

H_2 = image ray height for 50-percent vignetting

d_2 = diameter of lens L_2

S = separation distance between projector and receiver

f_2 = focal length of L_2

For the device that was fabricated, d_2 was 44mm, f_2 was 360mm, and S was approximately 1800mm, thus, H_2 was about 8.7mm. Since the CCD array was 12.5mm long, the vignetting diameter of 17.3mm (2 × 8.7mm) was adequate for the system.

The device fabricated by the authors used a simple 35mm slide projector with a 178mm focal length f/3.5 lens for the projector system. A 35mm slide of an "L" was used as the target slide. The receiver was custom built and housed all other component parts. The CCD element number readout was displayed on three-character segment display for each of the two channels.

OPERATIONAL EVALUATION

As stated previously the resolution or "least count" of this instrument was 0.07 mrad. To determine the repeatability of measurement, a windscreen was placed on a windscreen movement table; and two points were repeatedly measured by alternating between them. Thus, positioning accuracy of the windscreen movement table and the repeatability of the angular deviation device contributed to reading errors. Out of a total of 40 readings at each of the two points by two different operators (20 measurements each), the readings never varied by more than one digit or 0.07 mrad.

Measurements of F-16 windscreens using this device have compared quite favorably with data produced at other facilities using different techniques.

Although the system in its present configuration is successfully used in our laboratory, we are in the process of interfacing it to a microcomputer control system which will allow both automatic motorized azimuth and elevation positioning of the canopy, as well as digital recording of the associated position and deviation data on a computer disk. This modification will permit a very dense mapping of the entire critical area of the canopy with minimal human intervention. The digitally recorded data will then be processed to yield appropriate curves and graphs by simply removing the disk from the data acquisition system and inserting it into a second computer which is programmed to reduce these data to understandable terms. A similar feat was successfully performed in an AFAMRL Windscreen Program study of F-111 windscreens.

Section 4
FIELD USABLE MEASUREMENT DEVICE

Both grid board photographic techniques and the angular deviation measurement device are used under laboratory conditions to determine the optical parameters of newly manufactured aircraft transparencies. There appeared to be no accurate way to determine optical changes in these transparencies after the part was installed and while it remained on the aircraft. In a separate effort, the authors devised a method to allow measurement of several F-111 windscreen optical parameters with laboratory accuracy under field conditions. This method may be applied to any aircraft transparency with simple modifications of a positioning fixture (Genco, 1979).

DESIRABLE CHARACTERISTICS

The ideal field evaluation unit for optics evaluation would possess all of the following characteristics:

1. Measurement results taken with the field unit would be compatible with those taken under current quality assurance evaluation conditions.

2. Equipment would be easily portable, maintain its calibration, under field use conditions be easily and quickly installed with minimal effect on normal aircraft operational usage.

3. Automatic compensation would be included for slight alignment and lighting errors.

4. The system would be relatively foolproofed for operation by non-scientific technical personnel.

CURRENT TECHNIQUES

Current indoor photographic evaluation techniques for assessing optical quality of aircraft transparencies use large string boards or light boxes requiring considerable space, exact placement, and high electrical power demand. Special jigs or positioning devices are required to hold the transparency in its design position, and large format 4 inch × 5 inch cameras are usually employed for the photographs. As an example, F-111 windscreen acceptance photos are taken with the camera at design eye position and a grid board 10 feet from the forward arch (see Figure 8). Seid and Self (1978) have shown that photographic capture of transparency optical magnification effects (distortion) is most effective when the windscreen target distance is at least 2 meters. In the Figure 8 configuration, the required 135mm camera lens yields a photograph with a field of view of approximately 42 degrees × 50 degrees.

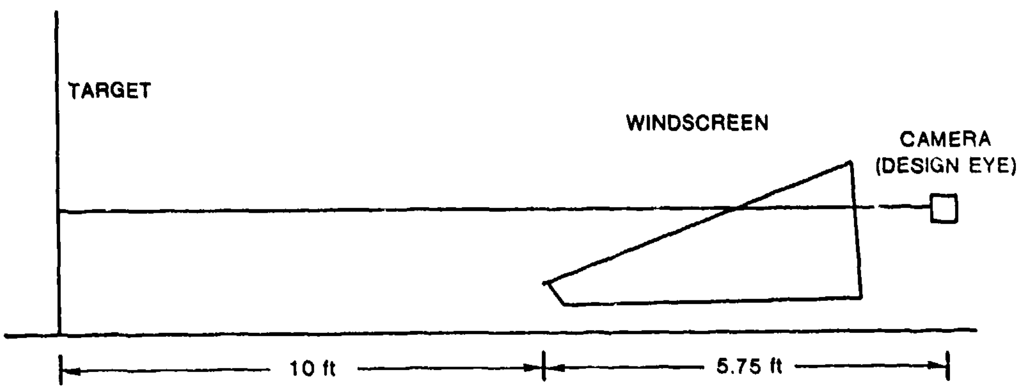

Figure 8. Typical Indoor F-111 Photographic Configuration

The target may consist of either 1 inch grid squares for distortion measurements, 6- or 8-inch grid squares for multiple image measurements, or a partially polarized screen for birefringence photos. Currently, AFAMRL uses a large light box to hold 6 feet × 6 feet or 8 feet × 8 feet back illuminated target panels that subtend an approximate 22-degree field of view. Most manufacturers use larger light boxes or string boards. Quite obviously, the

use of such a large grid board in field situations would be prohibitive; but a grid board of more manageable proportions would be either too small to examine a significant area of the windscreen in one photo, or it would have to be placed too close to the windscreen to reveal significant magnification errors.

EVOLUTION OF PORTABLE TRANSPARENCY OPTICAL TEST SYSTEM (P-TOTS)

At first, a rear projection screen was considered in which targets would be thrown on a screen held in front of the aircraft, and photos would be taken from the cockpit design eye position; but preliminary experiments indicated two major drawbacks:

1. The relatively low illuminance on the screen required that photos be taken in almost total darkness to avoid unwanted contrast degradation. In addition, long time exposures were necessary. During this time, screen movement caused significant image position shifts. Increasing lamp luminance increases heat and decreases the life expectancy of the slide. Also, we could not depend on calm nights uninterrupted by the appearance of disruptive vehicles or runway lights.

2. Polarization effects could not be studied due to the destructive effects of the screen upon polarized light.

Since both major problems appeared to be related to the projection screen, various materials that would yield high reflectance and maintain polarization were investigated. Eventually, a 3M product (Scotchlite No. 7611 High-Gain Reflective Sheeting) was found that acts as an excellent retroreflector in that the reflected light ray follows a path almost exactly like that taken by the incident light ray (Figure 9). The result of this circumstance causes much of the incident light to be returned to its source and yields a very bright image within an extremely narrow angle of return. Additionally, polarization of the incident light is not destroyed. Figure 10 shows that

the selected material has a luminance factor (gain) of about 1600 for on-axis measurements when the angle of divergence or angle between the incident and reflected rays equals 0. This compares with a gain of about .85 for white paper measured under similar conditions. The net result of this increased gain is a brighter target, permitting shorter exposures and solving most of the problems listed above. The narrow angle of acceptance also reduces the effect of extraneous light and attendant contrast reductions, thus allowing photos to be taken in relatively high ambient light conditions.

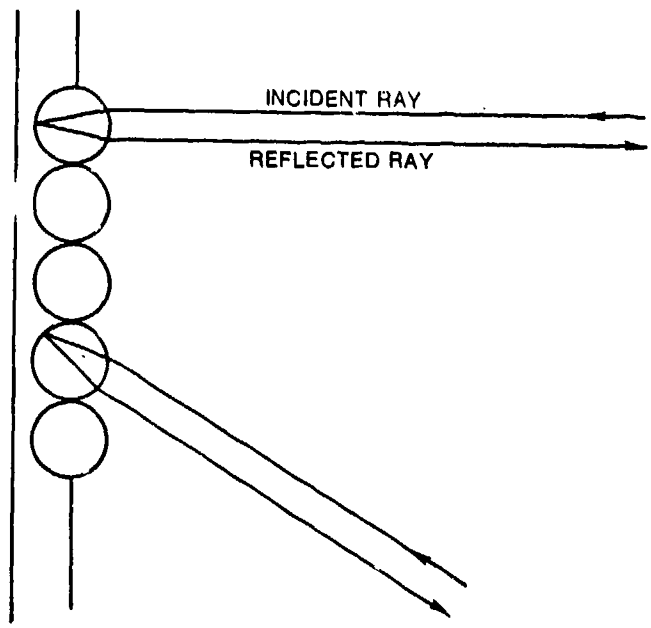

Figure 9. Retroreflective Effect of Screen

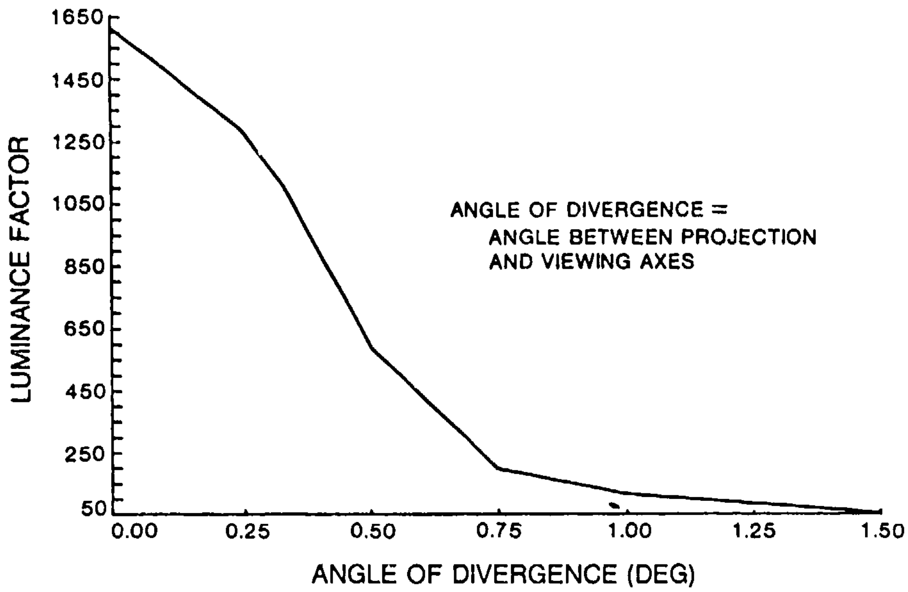

Figure 10. Effective Gain of Retroreflective Screen as a Function of Angle of Divergence in Degrees

Most projection screens would introduce some keystone distortion if not aligned perpendicular to the projection axis, and these same screens would produce a distorted image if they were buffeted by wind. The retroreflector used in the P-TOTS has been deliberately misaligned up to 45 degrees with negligible keystoning and has successfully maintained its imaging qualities under the most severe simulated buffeting conditions. These two factors insure that measured distortion is due to that introduced by the transparency rather than the reflective screens and will compensate for minor misalignment errors by field personnel.

Target slides were produced from high contrast, low grain, high resolution photographic transparencies of precision grid boards and mounted in plastic slide holders. A horizontally polarized target slide was also constructed that simulated skylight polarization (about 80 percent polarization). With this device, we could then determine any change in the birefringence pattern of the windscreen without waiting for repeatable sun angles. The slide format has an additional advantage in that it is much easier and less costly

to design a special pattern for capturing a particular optical problem with this format than with large grid boards.

The projection system (Figure 11) consists of an H3, 12 volt halogen lamp, an aspheric condensing lens, a modified 35mm slide holder, a 105mm f2.5 Nikon camera lens used as a projection lens, and a beamsplitter. The H3 lamp was chosen because of: (1) its ability to be oriented in such a manner as to present a point source to the condensing lens, (2) its resistance to the effects of shock and vibration, (3) its high intensity, (4) long service life, and (5) availability of 12 Vdc electrical power. The 46mm focal length aspheric condenser was intended to converge a significant amount of light onto the film plane. The Nikon lens is of excellent optical quality and is of such a size as to slightly overfill the retroreflective screen at a projection distance of 28 feet (28 feet was considered the minimum acceptable distance from design eye to just beyond the F-111 pitot boom). The low f-number of the lens provides sufficient light to fill the projection angle of 23 degrees. The beamsplitter allows the viewing or photographing path to be coaxial with the projection path; thus, the angle of divergence (Figure 10) is 0 degrees. Photos taken significantly off axis would suffer from light loss and keystone distortion.

The projected light passes through the windscreen to be retroreflected toward the source. This reflected light passes back along nearly the same path as that taken by the incident ray to again pass through the transparency and beamsplitter and finally focus on the film plane or eye (Figure 11). This optical arrangement, coupled with a precision mounting fixture to assure exact camera and P-TOTS positioning in the cockpit, allows accurate and repeatable observations of the following optical effects.

Birefringence

The light beam emerging from the P-TOTS can be polarized to a degree similar to that found at the aircraft's operating altitude. The reflected beam may be imaged on a color plate to show the effect of birefringence. An analyzer may be placed on the camera lens to enhance the saturation of the pattern.

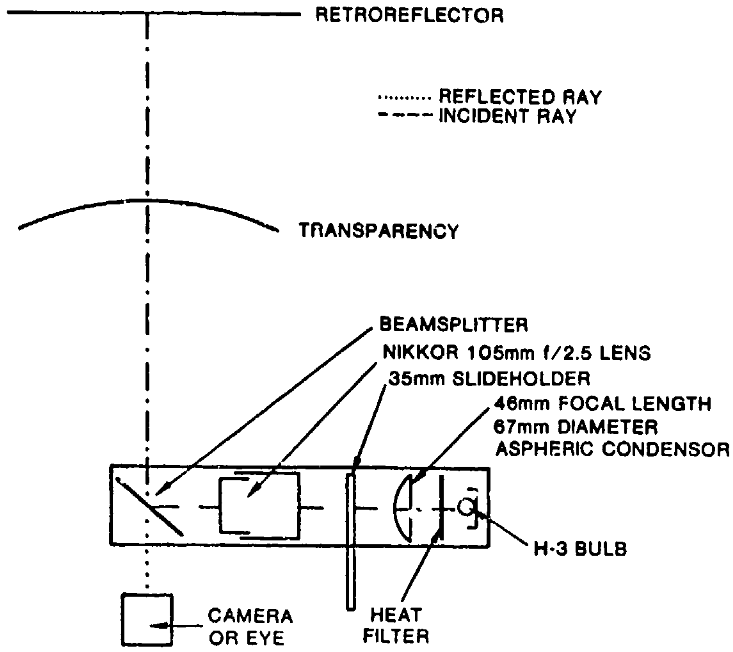

Figure 11. Schematic of the Portable Transparency Optical Test System (P-TOTS)

Distortion

An image of a precision 1-inch grid pattern is projected through the system. This image passes through the windscreen twice--once exiting the P-TOTS and once on its return path. Resultant photos are similar and related to those taken of standard grid boards; however, the absolute amounts of lensing may differ. This method is excellent for relative measurements, using a photo of the newly-installed transparency as a baseline and comparing subsequent photos to this baseline. Effects of stress-induced optical changes may be readily seen. Birdstrike damage and mechanical loading effects on optical parameters may also be depicted, as well as the effects of continued operational pressure and thermal cycling. Since photographic prints made with P-TOTS can be enlarged to a convenient size, presently accepted metrics of distortion (grid line slope, lensing, or displacement grad.) may be used.

We are presently evaluating the differences between amounts of distortion depicted by P-TOTS and various standard methods.

Binocular Distortion

The mounting fixture has two mechanical stops located 32mm on either side of design eye. These two positions represent the positions of a pilot's two eyes. The P-TOTS can be moved from one position to the other obtaining suitable single or double exposure binocular photos.

Multiple Imaging

Since the light passes through the transparency twice rather than once as in previous laboratory measures, twice as many multiple images are seen with the P-TOTS than with usual photos. This may be an advantage in that each pair of multiple images is antisymmetric and may allow a more exact measure of the distortion component by measuring the relative position of the two secondary images rather than measuring the secondary image with respect to the primary.

Haze

One of the greatest concerns of the Air Force is the life cycle costs of aircraft transparencies. One of the primary causes of replacement of aircraft transparencies is the optical degradation of the transparency surfaces. Environmental and maintenance caused surface problems result in a haze or halation effect which reduces the contrast of targets seen through the transparency. If the halation is great enough, targets at a considerable angular distance from the glare source may be effectively lost to view as the entire transparency appears to "light up." Present methods of measuring volume haze are both inadequate and inaccurate when applied to pilot perceived halation. P-TOTS is being configured to measure the haze in a manner which will portray the visual effects. A later paper will describe this effort.

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